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Diurnal variation in frequency response of gadoids in the Barents Sea

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Abstract

Earlier studies have demonstrated substantial diurnal variation in acoustic abundance of fish. Both the level and the uncertainty of abundance estimates from surveys carried out around the clock are affected. It has been hypothesized that diurnal variation in acoustic densities is caused by a diurnal variation in tilt angle. As the directivity of fish is higher at higher frequencies a diurnal variation in tilt angle will affect the acoustic recordings more for higher than for lower frequencies.

This hypothesis is tested through an analysis of the frequency response of acoustic recordings of cod and haddock in the Barents Sea from 18, 38, 70 and 120 kHz Simrad EK 60 echo sounders. The results demonstrate, as expected, a systematic diurnal change where the reduction in acoustic densities during nighttime is more prominent for higher frequencies. The result is expected since gadoids are visual feeders being active with a more directed swimming pattern at daytime than during night when they have a more relaxed swimming with more variable tilt angle. Applications of the results for improving the quality of survey abundance estimates are discussed.

Keywords: Frequency response, diurnal variation, gadoids, abundance, uncertainty

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INTRODUCTION

Due to the uncertainty caused by diurnal related variation some surveys are carried out only during daytime (see e.g. Karp and Walters 1994). As vessel time is expensive continuous operation is preferable for long oceanic surveys of economic reasons. Also, in an ecosystem perspective we need information from both day and night to enable quantification of diurnal related processes.

Hjellvik *et al.* (2004) found substantial effect of time of day on the estimated acoustic abundance; values being systematically higher at daytime. They considered the most probable explanation to be a change in the tilt angle from being more stable at day to becoming more variable during night. As acoustic target strength of swimbladdered fish is normally highest at low tilt angles (Nakken and Olsen 1983) the suggested explanation will give the observed result. Effect of tilt angle on backscattering is frequency dependent. At low frequency the fish is omni directional while directivity will increase with frequency (Nakken and Olsen 1983). Thus, if comparable backscattering values from several frequencies are available the relation between them will vary according to the variation in tilt angle of the observed organism.

In this paper we compare backscattering from five discrete frequencies to evaluate their variation over day and night. Only scrutinized data are used, i.e. the data have been categorised to species or groups of species. The objective is to evaluate the hypothesis proposed by Hjellvik et al. (2004) that diurnal variation in tilt angle distribution causes diurnal variation in acoustic abundance. Further, we discuss the potential of using multi frequency data to evaluate the quality of the scrutiny process and whether such information can be used to improve the scrutiny process.

MATERIAL AND METHODS

Acoustic data from 1334 nautical miles collected in the Barents Sea with R/V G.O. Sars in the period 10.-17 February 2005 were scrutinized at 5 different frequencies: 18, 38, 70, 120, and 200 kHz. Excluding miles with maximum depth larger than 300 m, 989 miles remained. The data were scrutinised at 38 kHz according to standard procedures (Jakobsen *et al*. 1998); noise from bottom and other sources were eliminated and the backscattering was allocated to species or categories (plankton, cod, haddock, herring, capelin, blue whiting, other demersal). Three scrutinized categories were analysed; cod, haddock and plankton, in addition to the sum of all scrutinized categories. We used the newest version of BEI (Korneliussen 2005) in the scrutiny and applied the noise reduction function prior to the multi frequency scrutiny. To secure a standard scrutiny all other frequencies inherited the 38 kHz standard, but each frequency was studied separately to avoid contamination caused by frequency dependent noise or disturbance. Small values are susceptible to contamination by minor undetected noise. Therefore we excluded miles with $\overline{s}_{A,tot} < 2$, where $\overline{s}_{A,tot}$ is the s_A integrated over the whole water column and averaged over all frequencies, the number of remaining miles was 989, 970, 496, and 426 miles for all species, plankton, haddock, and cod, respectively. The s_A was vertically integrated over 50 m depth layers. As a measure of frequency response, the fraction $r^f = s_A^f / (s_A^f + s_A^{f_0})$ was calculated for each depth layer at each mile, where f_0 = 38 and f = 18, 70, 120 and 200 are frequencies in kHz. If $s_A^f = s_A^{f_0}$, then r^f = 0.5, and we always have $0 \le r^f \le 1$. Depth layers with r^f = 0 or r^f = 1 were excluded from the analysis.

RESULTS

Diurnal response

The diurnal response is strong for the total backscattering as well as for all the studied categories (Fig 1). In general, as expected, the response of the 18 kHz is opposite of the other frequencies. In most cases the curves are peaking above 0.5 at daytime and remain below 0.5 at night for frequencies above 38 kHz while 18 kHz display the reverse pattern. The effect appears frequency dependent; the day extremes being sharper and more accentuated for higher frequencies than for lower.

Acoustic category effects

The results are surprisingly consistent among categories. Haddock display the strongest diurnal effect while cod seem to be least affected. The other fish species (herring, capelin, blue whiting, other demersal) behaved similarly as is indicated in Figure 1a including all scrutinized species. Surprisingly, the plankton category also in general had a similar diurnal response as the swimbladdered fish but this is layer dependent (see below).

Depth effects

Although the general trends are as described above we see a depth dependency through all the categories: the diurnal response is more accentuated for biomass distributed at deep water compared to further up in the water column. This is particularly apparent for plankton but the tendency is the same for the other categories. It is interesting to see that, in the 18 kHz comparison of cod the expected diurnal effect is apparent only for the two deepest layers, which host about 70 % of the scrutinized cod (Fig 1b). For the shallower layers there is no diurnal effect, or even a tendency to a reversed diurnal effect. A similar pattern is seen for haddock (Fig. 1c). The depth dependency seems to be most obvious for plankton (Fig 1d). At all frequencies, the deepest layers show similar diurnal effects as cod and haddock. The shallowest layer shows no strong diurnal response although it is noted that there is a tendency (probably not significant) for peaking at dawn and dusk for surface values at 70 and 120 kHz. The values in this layer are close to 1 for 18 kHz and about 0.8 for 120 kHz, which is much higher than the values in corresponding layers for 70 and 200 kHz. Values for the other layers are variable with no particular diurnal tendency. We also noted that night values for 200 kHz at deep water were generally lower than for 70 and 120 kHz.

DISCUSSION

In essence the results follow the expected pattern; a more variable tilt angle during night time causes a reduction in the average backscattering. The resulting day peaks are thus more pronounced with increasing frequency. Some exceptions and trends raise interesting questions that need further attention. What could cause the depth dependency? Are there a plausible reasons for the species/category related differences?

Before discussing the peculiarities of the results it is important to be aware of the limitations in using the higher frequencies at the deeper layers. In particular 200 kHz and possibly 120 kHz might suffer from a reduced effective sampling volume at these depths (Ona 1987). This might be the reason for the lower night values for 200 kHz in the deepest layers. The effect depends on threshold of weak targets at low densities. As the organisms are more scattered at night this could cause at least part of the observed diurnal variation. Part of the threshold

problem has possibly been avoided by excluding the lowest s_A values from our analysis. As the general pattern at the lower frequencies is maintained at the higher ones we do not expect that this effect seriously affect our conclusions

We expected similar effects for all swimbladdered fish species but anticipated a different outcome for the plankton category for which we expected a less pronounced diurnal effect. However, a clear diurnal pattern similar to that for cod and haddock was observed for plankton in deep water, but not in shallow waters. This depth effect for plankton needs attention. This category consists of small planktonic animal, which might very well include larval fish. Also misinterpretation or contamination could cause influence and in some cases a dominance of swimbladdered fish of different size. The problem of contamination is much more difficult to avoid in the deeper layers as various fish species and plankton are mixed and normally difficult to keep absolutely separate when using standard procedures for scrutiny. We are therefore not surprised that the plankton category in the three deepest layers behaves like fish while the plankton in the surface layer are less affected by the diurnal variations. In winter we do not expect larval fish in the upper 100 m and fish mixing is thus probably negligible as also is indicated by the time independency of the response. The high values for surface plankton for 18 and 120 kHz is difficult to interpret, as we have no species information but it could e.g. be caused by resonance.

The depth effect on fish is interesting. We see that the major part of the biomass behaves according to expectation. The reversed effect for cod and haddock in the shallower layers for 18 kHz and the reduced day peaks for the other frequencies might be caused by a depth dependent behaviour. For example we would expect such a result if the fish high up in the water column are hunting with a determined swimming behaviour during night while the bottom dwellers have a more relaxed behaviour with variable tilt angle.

These results are based on a preliminary study from a very limited part of 2006 Barents Sea winter survey data. There are all reasons to believe that the hypothesis of Hjellvik *et al.* (2004) plays an important role for the diurnal variation in acoustic abundance. However, to draw firm conclusions data from complete surveys over several years should be used. We want also to emphasize that such analysis might give new insight and understanding of behavioural characteristics of fish and plankton. Also, this approach could become a tool for improving interpretation of the acoustic data during surveying.

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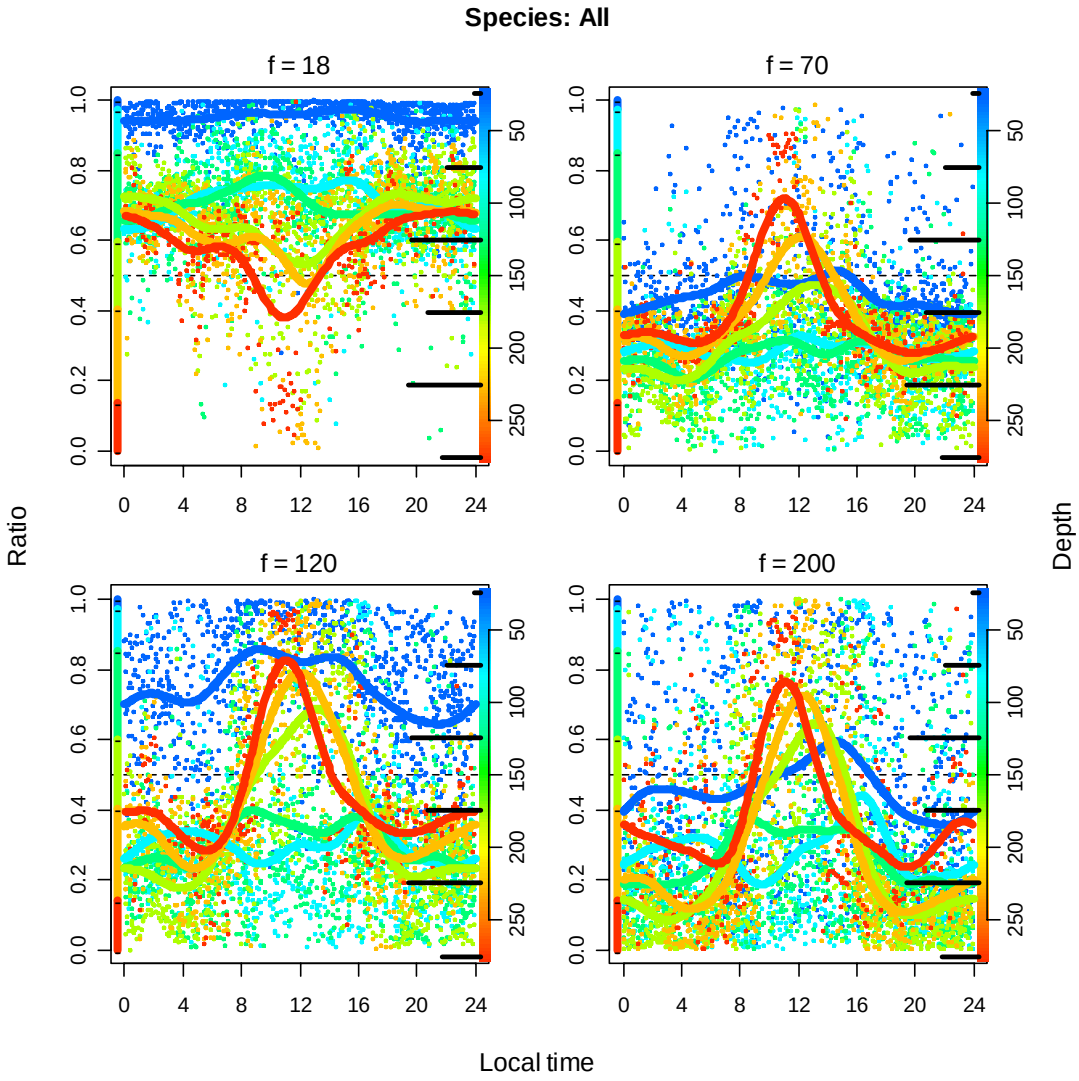

Figure 1a. Each point shows the ratio $s_A^f/(s_A^f + s_A^{38})$ for all scrutinized species joined together for one nautical mile at a given depth layer, where f = 18, 70, 120 and 200 is the frequency in kHz. The depth layers are 0-50 m, 50-100 m, … , 250-300 m. The colours indicate depth (scale at right margin). The horizontal bars on the right hand side indicate how s_A^{38} is distributed on the 6 depth layers. The lengths of the segments of the vertical bar on the left hand side are proportional to s_A^{38} in the corresponding layers. The curves are nonparametric estimates of the ratio $s_A^f/(s_A^f + s_A^{38})$ as a function of time of day. Only nautical miles where the total s_A averaged over all frequencies is greater than 2 are included in the analysis, and only depth layers where $s_A^f > 0$ and $s_A^{38} > 0$. The R function smooth spline with spar=0.8 was used.

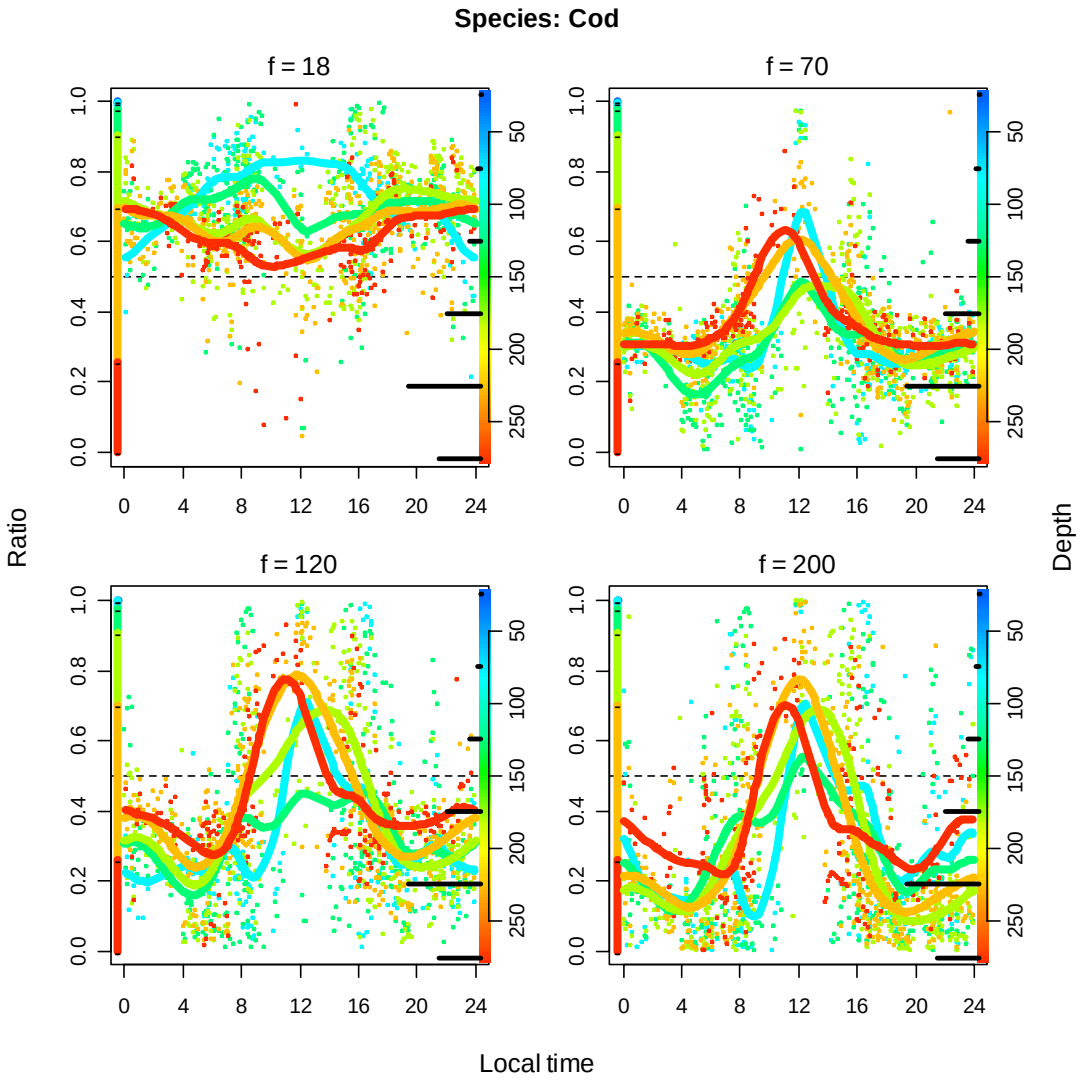

Figure 1b. Each point shows the ratio $s_A^f/(s_A^f + s_A^{38})$ for cod for one nautical mile at a given depth layer, where f = 18, 70, 120 and 200 is the frequency in kHz. The depth layers are 0-50 m, 50-100 m, … , 250-300 m. The colours indicate depth (scale at right margin). The horizontal bars on the right hand side indicate how s_A^{38} is distributed on the 6 depth layers. The lengths of the segments of the vertical bar on the left hand side are proportional to s_A^{38} in the corresponding layers. The curves are nonparametric estimates of the ratio $s_A^f/(s_A^f + s_A^{38})$ as a function of time of day. Only nautical miles where the total s_A averaged over all frequencies is greater than 2 are included in the analysis, and only depth layers where $s_A^f > 0$ and $s_A^{38} > 0$. The R function smooth spline with spar=0.8 was used.

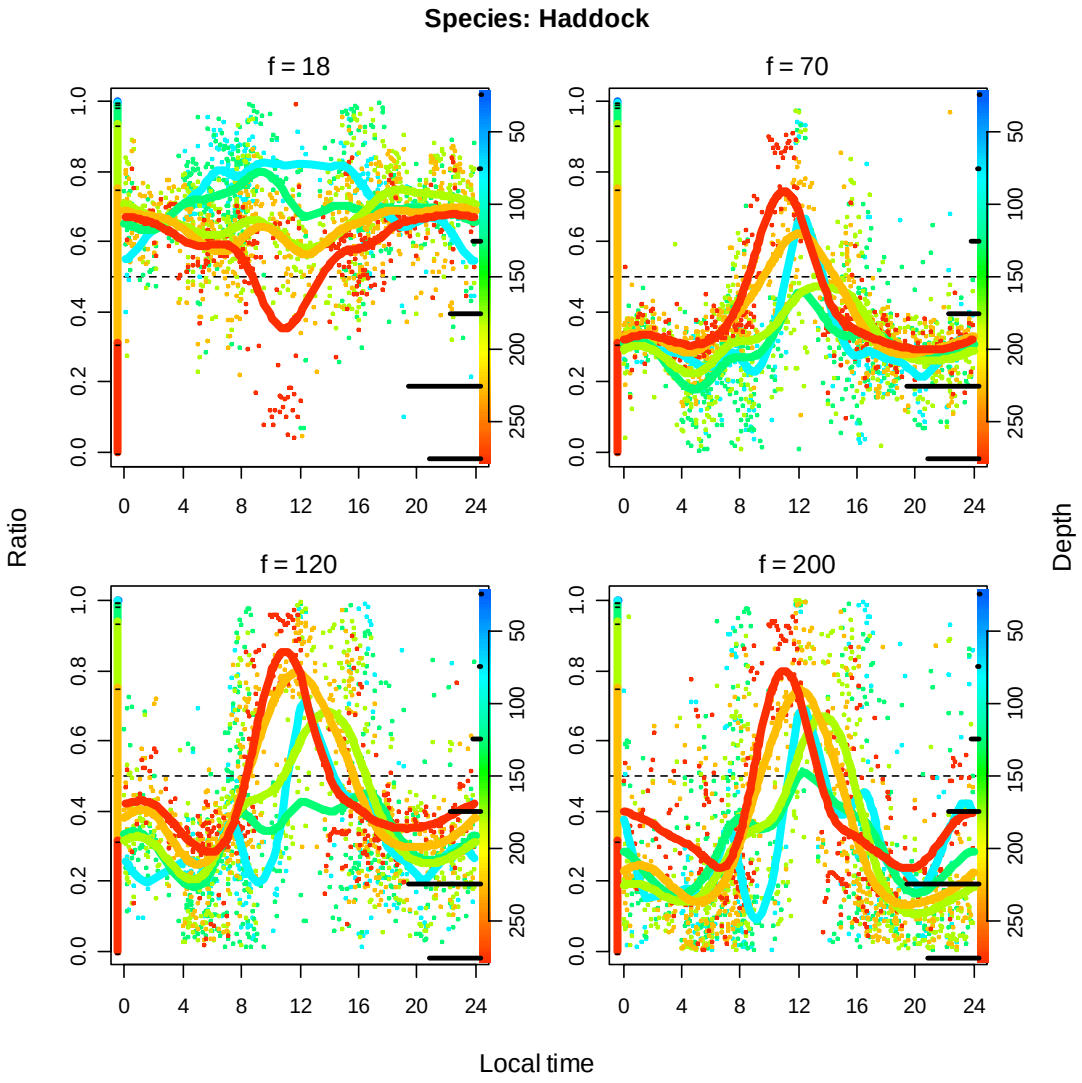

Figure 1c. Each point shows the ratio $s_A^f/(s_A^f + s_A^{38})$ for haddock for one nautical mile at a given depth layer, where f = 18, 70, 120 and 200 is the frequency in kHz. The depth layers are 0-50 m, 50-100 m, … , 250-300 m. The colours indicate depth (scale at right margin). The horizontal bars on the right hand side indicate how s_A^{38} is distributed on the 6 depth layers. The lengths of the segments of the vertical bar on the left hand side are proportional to s_A^{38} in the corresponding layers. The curves are nonparametric estimates of the ratio $s_A^f/(s_A^f + s_A^{38})$ as a function of time of day. Only nautical miles where the total s_A averaged over all frequencies is greater than 2 are included in the analysis, and only depth layers where $s_A^f > 0$ and $s_A^{38} > 0$. The R function smooth spline with spar=0.8 was used.

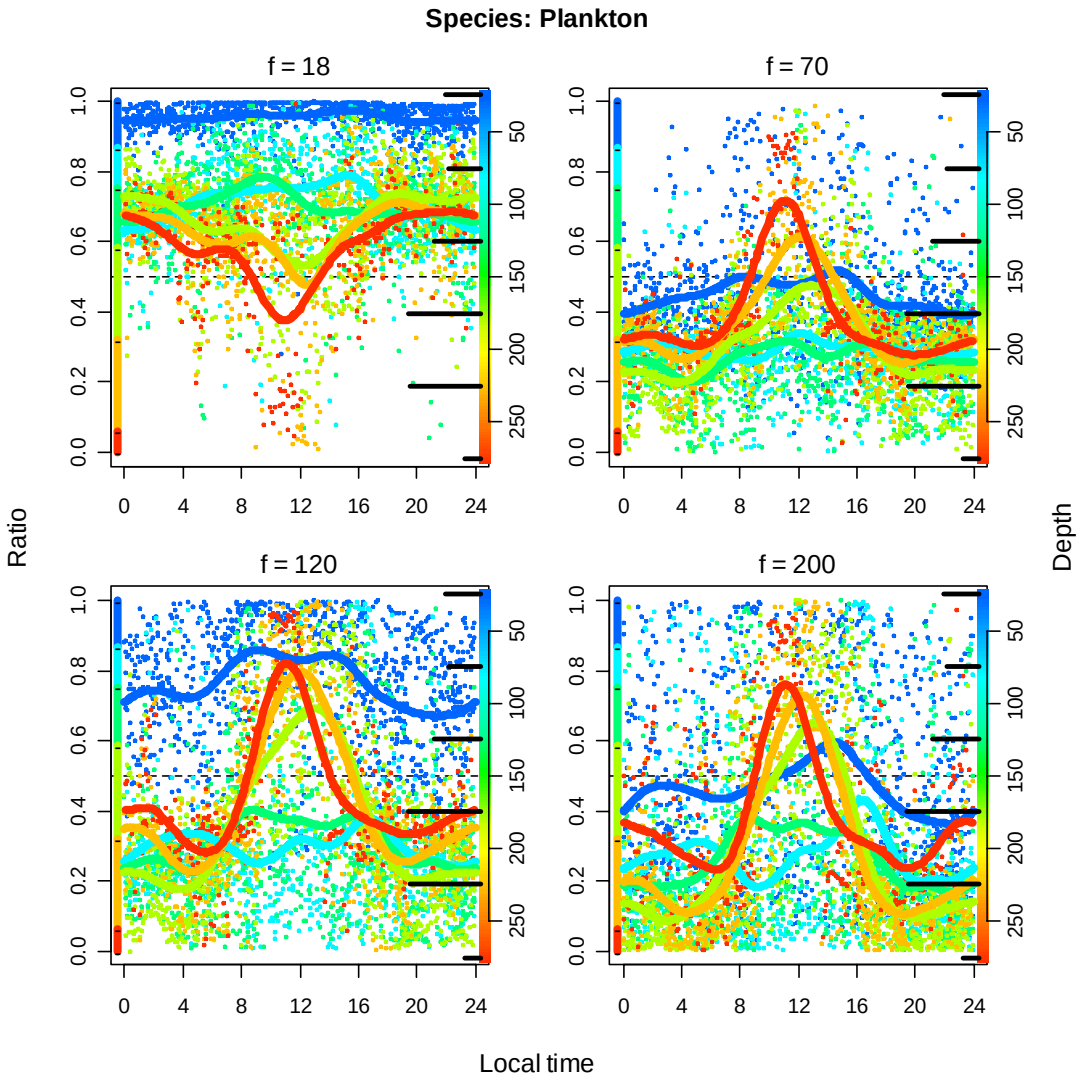

Figure 1d. Each point shows the ratio $s_A^f/(s_A^f + s_A^{38})$ for plankton for one nautical mile at a given depth layer, where f = 18, 70, 120 and 200 is the frequency in kHz. The depth layers are 0-50 m, 50-100 m, … , 250-300 m. The colours indicate depth (scale at right margin). The horizontal bars on the right hand side indicate how s_A^{38} is distributed on the 6 depth layers. The lengths of the segments of the vertical bar on the left hand side are proportional to s_A^{38} in the corresponding layers. The curves are nonparametric estimates of the ratio $s_A^f/(s_A^f + s_A^{38})$ as a function of time of day. Only nautical miles where the total s_A averaged over all frequencies is greater than 2 are included in the analysis, and only depth layers where $s_A^f > 0$ and $s_A^{38} > 0$. The R function smooth spline with spar=0.8 was used.